SOGNO

D3.4 v1.0

Description of initial Interfaces & services for autonomous and self-healing power systems

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Abstract
This document presents an overview of the services developed in the SOGNO project to provide self-healing features to the distribution grids and to give the forecast of the future consumption or generation patterns. The report highlights the main features of the developed services and focuses on the interfaces required to integrate them into the Virtualized Substation environment.

Keyword list
Self-healing distribution grid, Fault location, Service restoration, Load forecasting, Generation forecasting, Machine learning

Executive Summary

Deploying intelligence to achieve self-healing features and having accurate forecasts of future generation and consumption patterns are two main requirements for Distribution System Operators (DSOs) for managing emergency conditions and applying preventive countermeasures in order to avoid them. Innovative techniques based on artificial neural networks and deep learning can give a substantial contribution for implementing these functionalities and reaching such targets.

The objective of WP3 is the development of new data-driven intelligences for real-time or long term operational and business intelligence. This Deliverable takes care of the detailed description of the services. This includes the specification of the communication and information layers with the input/output formats. In addition, the interfaces required to enable them in the Virtualized Substation environment promoted in the SOGNO project are described. These interfaces are responsible for managing the interactions between the services via a publish-subscribe mechanism. These services and interfaces are thus the basis for advanced data analysis techniques for autonomous and self-healing systems.

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Table of Contents

1. Introduction

The project *Service Oriented Grid for the Network of the Future (SOGNO)* is funded by the Work Program H2020-LCE-2017-SGS. It has officially started in January 2018.

This deliverable provides the main concepts behind the two services developed in WP3 for giving self-healing features to the distribution grid, namely Fault Location Isolation and Service Restoration (FLISR) and Load/Generation Prediction (LP and GP, respectively). The report highlights the key aspects of the two services in terms of operational characteristics, data and sensor requirements, and outcome provided to the DSO. The different role of the two services to provide autonomous self-healing features to the electric system are also presented. The two services are integrated in the Virtualized Substation environment where, according to the SOGNO philosophy, all the power system intelligence runs. The interfaces required for the real-time operation of FLISR and in general for the coordination and integration of the services in the ViSA platform are described. Such details are relevant for the implementation phase performed in the WP4 of the project, before the deployment in the field, but also in general for the replication of the ViSA concept out of the SOGNO project.

1.1 Related Project Work

This report is based on the work done in the tasks T3.1, T3.2 and T3.5 of Work Package WP3. The first task (T3.1) focuses on the definition of new concepts for the development of autonomous and self-healing systems and, in particular, it investigates the application of big data analytics and deep learning architectures for the design of the WP3 services, namely Fault Location Isolation and Service Restoration, and Load/Generation Prediction. In T3.2, the new ideas are translated into the design of the services, while T3.5 deals with the definition of the data requirements and the interfaces needed for the integration of the services in the Virtualized Substation (ViSA) environment used to host the distribution grid intelligence.

The final design of the algorithm and the tests performed for its validation will be instead presented in the second phase of the project, in deliverable D3.3

The initial work this deliverable reports on will be used for the field trials on the various platforms. As shown below in table, certain services are tested at certain phases on these platforms: In the first phase, the LP/GP will be tested at Ericsson Estonia. The field trails will begin immediately after the end of the first design and implementation phase, which is at the end of 2018. In the second phase, both the LP/GP and FLISR services will be tested on the platforms shown in the figure below. The development for this phase will start in 2019 and the field trials will begin immediately after the end of the implementation. The report on the phase 1 implementation of the services described in this deliverable can be found in D4.2. The phase 2 will be included in D4.3. D5.2 will report on the results of the field and laboratory tests of the two phases, while D5.3 explores the scalability and performance of the evaluated results.

Table 1: Timescale field trials

	LOAD & GENERATION FORECAST	FLISR
ESB IRELAND (FIELD TRIAL)	Phase 2 in 2019	Phase 2 in 2019
CEZ ROMANIA (FIELD TRIAL)	Phase 2 in 2019	Phase 2 in 2019
RWTH GERMANY SMART CAMPUS (FIELD TRIAL)	Phase 2 in 2019	

RWTH GERMANY (LABORATORY TRIAL)		Phase 2 in 2019
ERICSSON ESTONIA (LABORATORY TRIAL)	Phase 1 in 2018	

Figure 1 shows the overall structure of SOGNO and highlights the main links of WP3 with the rest of the project. The self-healing services designed in WP3, together with the specifications on the required interfaces, are provided in input to WP4 for the integration in the ViSA before deploying the services in the field during WP5.

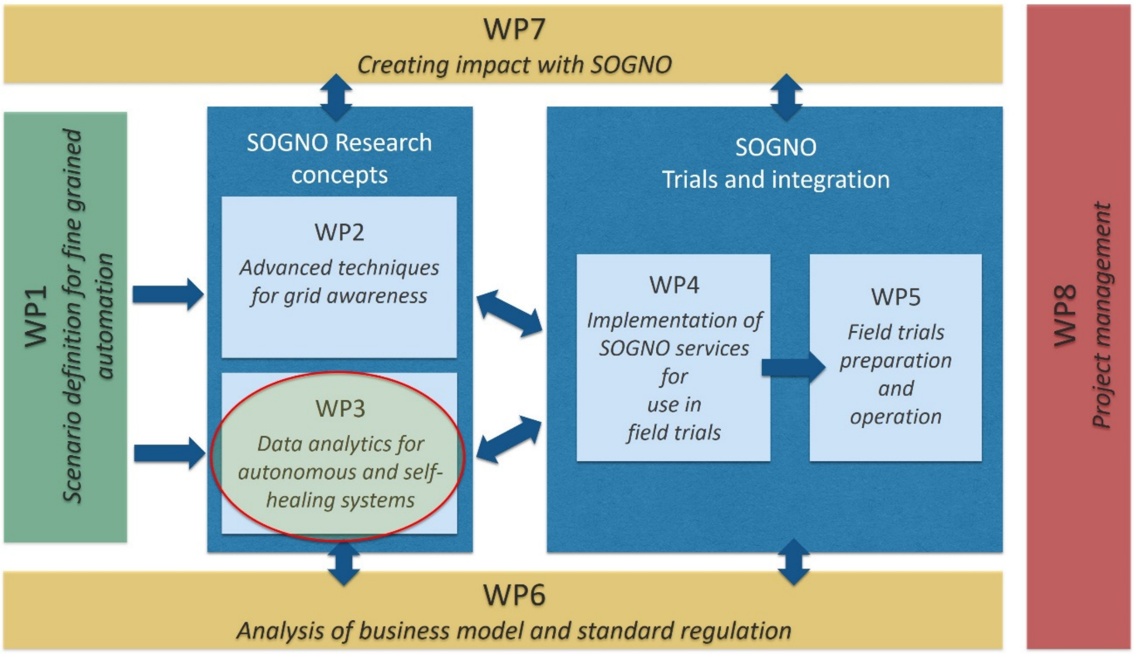

Figure 1: Overview of SOGNO activities.

1.2 Objectives of the Report

The main objective of this report is to provide the information needed for the implementation of the services for autonomous and self-healing systems, namely the Fault Location Isolation and Service Restoration (FLISR) and the Load and Generation Prediction (LP and GP, respectively) services. The goal is thus to present both the sensors and data requirements for the services as well as the specification of the interfaces needed for the integration of the algorithms within the Virtualized Substation (ViSA) environment considered in the SOGNO project.

1.3 Outline of the Report

The report consists of two main parts covering the service design and the identification of the required interfaces. The first part (Chapter 2) summarizes the main features of the services developed for autonomous and self-healing systems (FLISR and LP/GP). In particular, the main goals and data required/produced in input/output by the services will be described since such specifications are crucial for the following development and integration activities in WP4. The second part of the report (Chapter 3 below) provides a list of interfaces required for integrating the services in the ViSA, including an overview of the software components to be developed for the final deployment on the field.

1.4 How to Read this Document

This report follows D3.1, which already presented the new ideas behind the services designed in the SOGNO project for autonomous and self-healing systems, together with some starting implementation details referred to the use of advanced machine learning techniques. As a consequence, this Deliverable only provides a short summary of the main characteristics of the WP3 services (FLISR and LP/GP) and focuses more on the definition of the measurement/sensor, data and interface requirements, which are the reference for the following integration in the ViSA. For a complete overview of the WP3 services, the following Deliverables should be read together with the present one:

- D3.1 – Description of new SOGNO techniques for autonomous and self-healing power systems (M10): it includes a description of the application of artificial neural networks and deep machine learning concepts for the development of the FLISR and LP/GP services.
- D3.3 – Validation and description of the techniques, interfaces and services for autonomous & self-healing power systems (M22): it will present the final design of the services together with off-line tests performed for their validation before the deployment on the field.

Moreover, for a more general view of the scenarios and services considered in the SOGNO project, a comprehensive description is provided in the following Deliverable:

- D1.1 – Scenario & architectures for stable & secure grid (M12): it includes a description of power system scenarios investigated in the project, with motivations for the services presented in this deliverable both for current and future distribution grids.

Last but not least, it is worth noting that this Deliverable provides the description of the components and interfaces required within the ViSA platform. Since the ViSA is used to host both the self-healing services described in this deliverable and the system awareness services designed in WP2, several components and interfaces in the cloud platform are the same and therefore similar descriptions appear here and in D2.2:

- D2.2 - Description of initial Interfaces & services for autonomous and self-healing power systems (M12)

2. Autonomous services for self-healing

2.1 FLISR

Via the Fault Location Isolation and Service Restoration (FLISR) service, the power grid earns the capability to detecting any fault occurring in the grid, and instantaneously taking the appropriate reactions to minimize the number of customers affected by the disservice. The appropriate reactions are in the form of isolating the faulty part of the grid and making sure that any other part of the network that is not directly interested by the fault is immediately reconnected to the main grid. Differently from traditional procedures that involve a grid operator for understanding what occurred in the grid and for applying the network reconfiguration, a FLISR algorithm aims at performing all the tasks of fault location, isolation and service restoration in a completely autonomous manner, thus providing self-healing features to the grid.

The FLISR service can be divided in two main parts: the first step is the fault detection and location; the second part is the isolation of the faulty area and the restoration of the service in the other parts of the grid. For the first task, namely the fault location, the FLISR algorithm initially requires a logic to detect when a permanent fault occurred in the grid, which is the trigger for the execution of the subsequent steps. When a permanent fault happens and is detected, the location of the fault has to be identified. To this purpose, different techniques have been proposed and investigated in the literature, such as the use of Wavelet transforms, impedance-based methods, wave propagation analysis, etc. In SOGNO, the idea is to apply innovative techniques based on advanced machine learning. The reason for investigating the possibilities offered by this type of solutions are that smart data-driven techniques can be the most suitable to understand the fault location based on a minimum amount of information available on the field, as it usually is the case at the distribution level of the electric system. The design of the fault location part can be partially customized on the basis of the particular data that can be available from the field. In general, however, signals and measurements related to the fault conditions need to be provided to the fault location algorithm to perform its task. The same quantities that would be received from the field in case of fault, need to be used for the training of Artificial Neural Network (ANN) or other machine learning based procedure. These quantities can be the voltage, current and/or power flow being measured at different points in the grid via appropriate sensors and phasor measurement units, or alternative measured data. During the training of the algorithm, the goal is to capture the behaviour of the grid in the form of these quantities under each possible fault in the grid, so that when a fault occurs in the reality, the algorithm can be automatically able to associate to it the characteristics and location of the fault.

The second part of the FLISR procedure includes the isolation of the fault and the service restoration. To apply these steps, the FLISR algorithm requires the detailed knowledge of the network topology and its characteristics in the form of lines, nodes, installed reclosers, switches, etc. Relying upon this information, once the location of the fault is identified by the first algorithm block, the isolation and restoration sections decide the optimal change (reconfiguration) of the network topology necessary to isolate the fault (i.e. to make sure that the faulty area is kept without any power supply) and to restore the power supply to all the other areas of the grid.

Machine learning and data driven field provides promising methods and algorithms for a proper implementation of this service. Initial tests and experiments have been conducted in WP3 and are described in deliverable D3.1. The final design of the algorithm and the tests performed for its validation will be instead presented in the second phase of the project, in deliverable D3.3.

2.1.1 Data requirements

The FLISR is a complex service that, for its operation, requires detailed information on the grid and specific measurement information collected from the field during the occurrence of the fault. Different data can be needed for the different steps of the algorithm or in different stages of the design. The first part of the FLISR is the fault location. This is the most crucial step, because the correct application of the following isolation and service restoration procedures are fully dependent on the accuracy of this information. The machine learning algorithm devised in SOGNO for fault location needs a starting training phase for “learning” the behavior of the grid resulting from the occurrence of faults in possible different locations. To this purpose, power system simulations are needed to reproduce the behavior of the grid in faulty scenarios and, therefore, the detailed model of the grid is required in input. Such a grid model includes not only the topology of the grid, but also the detailed characteristics of lines (series impedances and shunt admittances) as well as the information on the grounding characteristics of the network. The location of the meters available to provide data relevant for the faulty conditions is also required. After the training and validation stage, the FLISR can be deployed on the field, where it will work by processing the measurement information gathered in from the field during the occurrence of the fault. Sensors and measurement units with real-time data communication capabilities are thus needed. The electrical quantities to be provided by the measurement units can vary but, in general, voltage, current and power measurements are quantities that could be used to feed the machine learning algorithm. Once the fault location is obtained, the following steps are the fault isolation and the service restoration. These procedures are carried out by applying a network reconfiguration, which implies the control of the opening or closing status of controllable switches in the grid. The input data required for the application of this routine are therefore the location of the different controllable switches in the grid, together with the knowledge of their status. As a matter of fact, the FLISR algorithm thus needs to have a bi-directional communication with the field: on one side to receive the measurement data when the fault occurs, and on the other end to send the opening or closing commands to the switches for reconfiguring the grid and, consequently, obtaining the isolation of the fault and the restoration of the power supply in the non-faulty areas.

2.1.2 Sensor and measurement requirements

In electric power engineering, a fault occurs when an abnormal electric current is present. This condition takes place, for example, when the dielectric insulation around a conductor is broken and the current can bypass the normal load, passing directly to the ground or to other conductors. Also the line voltages are affected: as an example, in a grounded system, during a single phase to ground fault the voltage to ground potential of the other phases can increase to be nearly twice the nominal one.

Being able to acquire properly voltage and current waveforms during a fault is non-trivial task: the commonly used iron-core transformers have low dynamic range due to the core saturation. This phenomenon limits the maximum current that the transformer can acquire, so normally one transformer is designed for the nominal current and it is used for accurate current measurements (measurement transformer), and another one, in series, is designed for 20 or 40 times the nominal current and it is used for fault detection (protection transformer).

To avoid the use of two transformers, the current sensor should be based on a Rogowski coil. In this air-core transformer the low voltage signal output is proportional to the rate of change of the electromagnetic field generated by the current carrying conductor, usually passing through the secondary coil. As a non-magnetic core is used, the Rogowski coil accuracy is not affected by core saturation and it is maintained even if the primary current is hundreds of times higher than the nominal one. This notable performance makes the Rogowski current sensors suitable for both metering and protection. In a very similar way, the voltage sensor should be able to acquire correctly a voltage considerably higher than the nominal one, maintaining an excellent accuracy in normal conditions.

For these reasons, a maximum voltage of 1.9 times the nominal one, and a maximum current of 20 times the nominal one should be acquired properly by the sensors.

Merging these requirements with those reported in D2.2, following the new standards on passive sensors: IEC 61869-10, relevant to Passive Low-Power Current Transformers (LPCTs) and IEC 61869-11, covering Passive Low-Power Voltage Transformers (LPVTs), the sensors accuracy class is fully defined:

- Current sensors: class 0.5P, whit current factor (k_{PCR}) equal to 20, for power quality application;
- Voltage sensors: class 0.5S, with voltage factor (F_V) equal to 1.9, for power quality application.

	0.02 Upr	0.2 Upr	0.8 Upr	Upr	1.9 Upr
Ratio Error ±[%]	2	1	0.5	0.5	0.5
Phase Error ±[mrad]	24	12	6	6	6

Limits of ratio error and phase error for voltage sensors of 0.5S accuracy class (IEC 61869-11)

	0.01 Ipr	0.06 Ipr	0.2 Ipr	Ipr	20 Ipr
Ratio Error ±[%]	1.5	0.75	0.5	0.5	0.5
Phase Error ±[mrad]	27	13.5	9	9	9

Limits of ratio error and phase error for current sensors of 0.5P accuracy class (IEC 61869-10)

It is worth noting that, during an electric fault, a lot of harmonic components are generated: often the accurate acquisition of these components is fundamental to estimate the fault location with an acceptable precision [1]. The new standard IEC 61869-6 reports sensors' requirements for these applications, but as there is not a general consensus at the moment, the frequency limits have to be determined on the basis of each application.

As an example, in SOGNO project the sampling rate of the acquisition system is limited 62.5 kS/s, so a maximum frequency of 31.25 kHz can be acquired. On these bases, we can define the following specifications:

	< 3.125 kHz	31.25 kHz
Ratio Error ±[%]	10 %	30 %

Limits of ratio error for current and voltage sensors for special high bandwidth protection (IEC 61869-6)

This bandwidth requirements will be confirmed, or revised, when the FLISR algorithm will be completely defined.

2.2 Load/Generation Prediction

The Load Prediction (LP) and Generation Prediction (GP) are two important services, which help to have a reliable and stable power network. The load and generation prediction services provide the power network with detailed information about the future power demands and generated power, respectively, which helps in power planning and operation. While the FLISR service provides autonomous self-healing features by reacting to the occurrence of a fault event, the LP and GP are instead important to forecast the possible occurrence of contingencies or other operational issues in the grid. In this way, they can thus enable “preventive” self-healing procedures that anticipate the possibility of a problem in the grid and take timely actions to prevent such an event.

The LP and GP work by processing historical data of consumption or generation, respectively. The historical information can be represented as time series data, and it can be available with different sampling rates (for example 1, 5- or 10-minutes sampling rate). Based on this starting information, the task of the LP and GP services is to learn what is the typical pattern of consumption or generation and to predict, accordingly, the expected behaviour of load and generation nodes in the future. The predicted information will be typically in the same rate as the available historical data. The horizon for the prediction can largely vary, also depending on the specific purposes of the forecast. As an example, for strategical planning decisions, a DSO can desire to have the prediction of the loading or generation conditions in the following years, and in this case the prediction would be a long-term forecast which could also accept a lower resolution of the data. For the application of preventive self-healing logics, as in the aims of SOGNO, the goal is instead to have a short-term forecast to understand if possible issues can arise in the operation of the grid for the following day or in the next hours. As a consequence, the LP and GP target for SOGNO has been chosen to be the provision of the day-ahead forecast, namely the prediction of the power consumption or generation at a specific node or substation for the following day.

For their nature, machine learning methods fit very well for the design of the LP and GP services. Both services can be implemented using machine learning based models, which utilize sufficient historical information to understand the behaviour of the data in hand to provide their values at future time slots. In the case of the LP service, the historical data is in the form of the power demands at past instances, which is utilized to predict the demands at future time slots. On the other hand, the past or historical power generated from any renewable energy source system (in our case photovoltaic systems will be taken into consideration) and the corresponding weather conditions are used to predict the generated power at future time slots taking into account the availability also of weather forecasts. Different weather variables can be taken into account for power generation prediction. For example, air humidity, temperature, solar irradiance, can all be inputs for the training of the machine learning algorithm. Their possible use will be evaluated based on their importance in the prediction process, and how directly they affect the prediction performance. A first explanation of the machine learning based models used for both LP and GP services can be found in deliverable D3.1. Moreover, deliverable D1.1 presents the general power system and services' requirements.

2.2.1 Data requirements

As mentioned earlier, both the LP and GP require historical information as input, in order to predict the appropriate information at future time slots.

To be more specific, the LP service requires input information like the electricity consumption (demands) measured at previous (past) time slots. Such historical data is read from electrical power meters placed at certain locations in the network. In case of power meters shortage or unavailability, the output of state estimation (SE) service can be utilized to calculate the power load at different time slots. At the end of the day, the LP service understands the pattern and the behaviour of the power consumptions (demands) in order to predict the demands at future time slots.

On the other hand, the GP service requires as input the combined information about the generated power in a certain photovoltaic system at past time slots along with the corresponding information on the weather conditions present at that time, such as the solar irradiance, temperature, humidity, etc. The GP service will be trained to understand the relationship between the generated power and the corresponding weather conditions. As a result, the GP service will predict the generated power at future time slots, given the weather forecast. The weather information (historical or forecast) can be obtained from an online weather forecast provider.

In summary, it is worth noting that the LP and GP services do not have very strict requirements in terms of data input. For example, no real-time data communication from measurement devices in the field is necessary, since the services only access the consumption/generation data only a posteriori. Moreover, no specific data on the grid is required, since the forecast is performed on the single consumption/generation nodes and this is not affected by the particular topology or characteristics of the grid.

2.2.2 Sensor and measurement requirements

As previously anticipated, the LP and GP service do not need real-time communication from the measurement devices on the field. Moreover, no very strict accuracy and measurement requirements exist in general. In SOGNO, since the measurement devices available on the field will be used to enable state estimation, the same sensor requirements presented in D2.2 for the state estimation service can be taken into account as a reference for the choice of the sensors.

3. ViSA components and interfaces

According to the SOGNO vision, the autonomous self-healing services described in Section 2 will be integrated in a Virtualized Substation (ViSA) environment where all the distribution grid intelligence will be working. One of the main benefits of the ViSA solution is the possibility to flexibly interconnect several components to guarantee interoperability between the different services. Several components and interfaces are necessary in the ViSA platform to ensure the receiving of measurement data from the different devices on the field, the persistence of data in the databases, to manage the communications between services and the sending of results back to the devices in the field or to a graphical user interface to allow the visualization of events to the grid operator. The identification of these components and of the associated interfaces is important to guarantee the complex communication between the services. In this Chapter, the specification of the main components and interfaces needed to enable the autonomous self-healing services will be provided. It is wort noting that, since the ViSA is expected to host both the self-healing services described in this deliverable and the system awareness services presented in D2.2, several of the components and interfaces here presented are the same as in D2.2. Whenever implementation details or interfaces specific for the services defined in this deliverable are required, this will be highlighted to give a clear idea of which components cover general tasks and which one are service-specific. The detailed description of the implementation and of the specific software solutions adopted for the components and interfaces here described is provided in Deliverable D4.2. The following figure gives a high-level overview of the ViSA structure and illustrates the communication logic between the components.

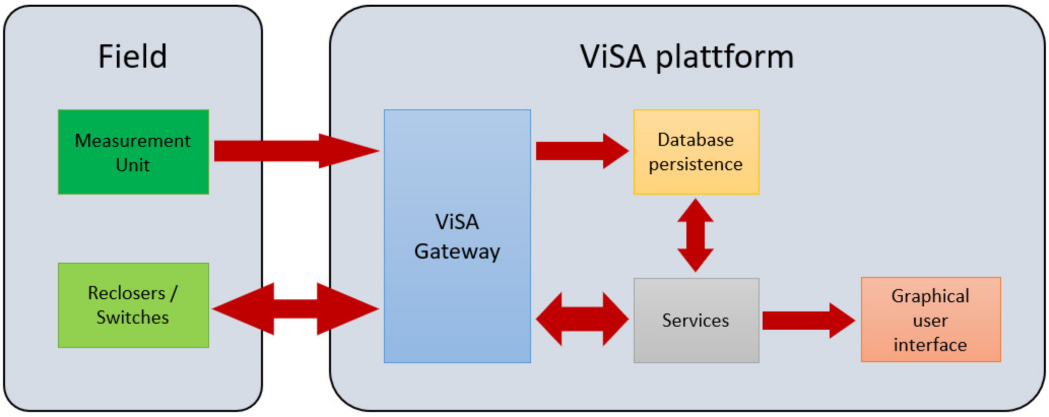

Figure 2: Communication logic between the components.

Figure 2 shows a schematic view of the main components involved in the operation of the different services. In the following, the components will be described according to their logical role and the specification of the needed interfaces will be provided emphasizing the relationship to the services described in Section 2**Fehler! Verweisquelle konnte nicht gefunden werden.**.

3.1 Field components

Measurement units are the components on the field providing the data needed to enable the LP and GP services. For the FLISR, in addition to the measurements, it is necessary to have the bi-directional communication with reclosers and switches in order to receive the notification when a switching event occurs and to have the possibility to apply opening or closing actuation commands during the phase of fault isolation and service restoration. The SOGNO solution allows accommodating different types of measurement devices and can enable the bi-directional communication towards the components on the field, as required by the FLISR service. Concerning the integration of measurement devices, while in SOGNO the focus is on the development of low-cost measurement units that can also be easily customized, in general, the ViSA platform can interact also with off-the-shelf meters and components available in the market.

No specific modifications are needed for the components in the field to talk with the ViSA: their only requirement is to have real-time data communication capabilities (note that this is required for the FLISR service, while the LP and GP services, theoretically, do not have strict requirements from this point of view). All the intelligence needed to handle the communication, to translate the specific protocols used by the field devices and to extract the data needed by the services is directly embedded into the ViSA platform. Such a solution is thus able to guarantee the interoperability among different devices and hardware manufactured by different vendors.

3.2 ViSA Gateway component

The ViSA gateway is the component allowing the communication between measurement devices or other possible components deployed on the field and the intelligent services in the cloud platform. This component needs to be able to receive the measurements (and also to send control commands in the case of FLISR) in different formats or protocols according to the languages supported by the devices on the field. Moreover, since the FLISR (as well as the system awareness services described in D2.2) have to work in (near-) real-time, the gateway has to ensure that the data communicated by the instrumentation on the field are immediately transferred to the services for their prompt processing. To ensure this, different interfaces are needed in the gateway, as described below. Figure 3 gives a schematic view of the interconnections among the different interfaces in the ViSA gateway described in the following, with the indication of the direction of the communication flow: It is worth noting that the same operation logic, and therefore also the same software interfaces, are needed in the gateway to enable both the self-healing automation services presented in this Deliverable and the system awareness services presented in Deliverable D2.2. As a consequence, the following description follows the same details provided in D2.2.

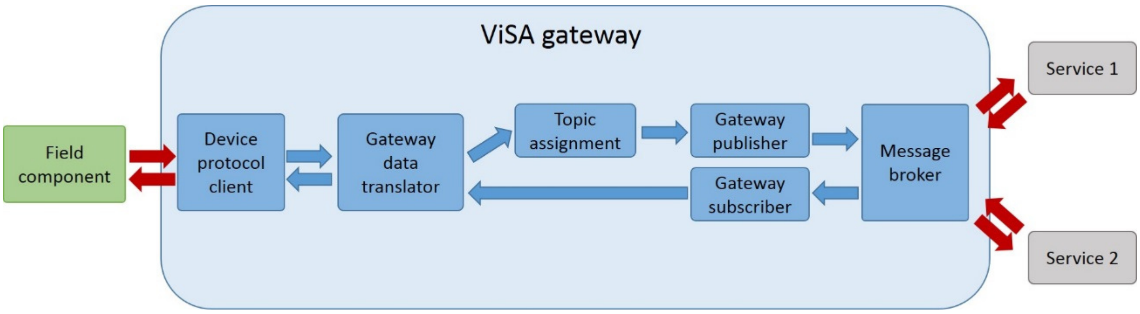

Figure 3: Schematic view of the software components in the ViSA gateway.

- **Device protocol client:** this is in general the interface for the communication with the field components. Communication clients need to be available for each one of the communication protocols used by the devices on the field so that the communication with them can be correctly activated. For example, in case of the LP and GP service, measurement devices can send their measurement data via IEC 61850 protocol or with the PMU IEEE C37.118 synchrophasor format: a client able to listen to these communications is therefore needed in the ViSA gateway as direct interface towards these measurement components. Similarly, in the case of FLISR, the communication from/to the reclosers and switches need to be done following a specific protocol, which depends on the communication format supported by the devices in field: suitable protocol clients are thus needed also in this case.

- **Gateway data translator interface:** the ViSA platform needs to handle internally different data, which are coming from the measurement units on the field, from the outputs of the service algorithms, and so on. For this reason, specific internal transport protocols and data formats will be used within the ViSA, which will be in general different from the data formats used by the communication protocols of the field components. A data format translator is thus needed to ensure the correct translation of the data from/to field components to/from the ViSA platform. When the data flow is from the field devices to the ViSA, the data format translation interface takes care of the extraction of the relevant data provided by the device protocol clients and it converts them into the data format used within the ViSA. As an example, JSON (JavaScript Object Notification) format is a lightweight and flexible format that can be used for data interchanging within the ViSA. On the contrary, if the data flow is from the ViSA to the field devices (for example, in case of the PC service, for sending an actuation command to the DERs), the data format translator takes care of the conversion from the ViSA data format to the specific format needed in input to the associated device protocol client. Obviously, since different communication protocols can be used by the devices on the field, specific data format translation interfaces can be needed for each one of the communication protocols to be supported.

- **Topic assignment interface;** this is an interface that is used only for managing the communication flow from field components to ViSA. In general, data coming from the field can be different (measurements, switch event notification, etc.) and they can be required by different services according to their nature. In the ViSA, the routing of the data to the different ViSA components is performed using topics. The logic is that each ViSA component can subscribe to receive the data communicated under a certain topic, so that only the information of interest is received. To guarantee the coordination of the communication according to this logic, a topic assignment interface is therefore needed on the ViSA gateway for assigning the desired topics to the specific data arriving from the field devices. This interface is thus responsible for assigning the correct topics to the payloads from the data streams in order to forward them to the correct services.

- **Gateway publisher interface:** in order to guarantee the real-time communication of the data from the field component to the services, a publish/subscribe mechanism is used within the ViSA as communication paradigm. Data are always published using a specific topic, while the ViSA components can subscribe to different topics for getting only the data that are important for their operation. Different communication protocols can support the publish/subscribe mechanism, and MQTT (Message Queue Telemetry Transport) is an example of widely used protocol based on this solution. The main task of the gateway publisher is to wrap the data received from the data format translator and topic assignment interfaces with the decided publish/subscribe communication protocol and to forward these data to the message broker (described later).

- **Gateway subscriber interface:** since the ViSA gateway has to ensure the bi-directional communication between cloud platform and field, a subscriber is needed to get the data (for example the output of the FLISR service, since this needs to be sent back to the reclosers and switches in the field in order to apply the fault isolation and service restoration) that need to be forwarded to the field components. The gateway subscriber has thus to subscribe to the relevant topics and needs to forward the received data to the data format translator interface for enabling the sending to the field components.

- **Message broker:** the message broker is a key component in the publish/subscribe communication paradigm. It is the actor responsible for getting the data published by the information producers and for forwarding them to the right components according to the received topic subscriptions. As a matter of fact, this is therefore the key component allowing the proper coordination of the data routing and guaranteeing that data are forwarded as soon as available, thus guaranteeing their (near-) real-time communication. The message broker plays a vital role for enabling the bi-directional communication between field components and ViSA services. In fact, data from the field are published through the ViSA publisher interface and then forwarded (via the message broker) to the relevant services. On the other hand, for the sending of actuation commands from the services to the field components, the services will publish the command and this, via the message broker, will be forwarded to the ViSA subscriber interface. In this way, the bi-directional communication between field and ViSA services can be enabled and guaranteed in (near-) real-time. It is worth noting that, in the developed solution, the message broker will not be only responsible for the coordination of the communication between field and ViSA services, but also for the re-routing of all the communication internally to the ViSA. As an example, the results of the LP and GP services could be automatically forwarded to specific data analytics tools responsible for evaluating the future operating conditions and for detecting the risk of issues or contingencies at future time slots. The coordination of this communication can be enabled automatically thanks to the message broker. In this example, the LP and GP services will publish their results and the specific data analytics tool responsible for the described task (which needs to be subscribed to the topic associated to the LP and GP results) will receive these data via the message broker.

3.3 Database persistence component

This component stores all possible information in a database so that network operators have the possibility to access historical data and service results. To ensure this, data produced from the measuring devices, services and the network model will be stored directly here. In the case of the self-healing services described in this deliverable, both the results of FLISR and LP/GP will be stored in the database for possible a posteriori analysis. Moreover, the database plays a key role in the case of the LP and GP services, since it is the component containing the historical data needed for the activation of this service. In general, two different types of database will be used within the ViSA platform.

- **Static database:** this database is specifically set-up for the storage of all those data that are static and are not going to change during time. All the information about the grid data, the measurement devices characteristics and other field component characteristics (for example, position of switches or reclosers) will be thus stored in this database. In particular, as for the grid data, the Common Information Model (CIM) will be used. This format makes easier the exchange of data among different applications and platforms and allows a comprehensive modelling of the grid information. The CIM is object-oriented and consists of classes, attributes and relationships among them to describe the behaviour of the electrical system components. These data are an essential inputs for the FLISR algorithm, since both the fault location step and the following fault isolation and service restoration phases require specific information on the grid for their operation.

- **Time series database:** both live measurement data and the results of the services will be stored in this database, which is specifically conceived to manage in an efficient way large time series of data. This database must be highly scalable and resilient to satisfy the requirements of the network operators.

In SOGNO, the access to the database is handled in a different way, depending on whether a request/response action is performed to get, write or modify some data (as required for example by the LP and GP services) or if the purpose is to write the real-time data coming from the field devices (collection of measurements later used as historical data from the LP and GP services) or in output from the services (like in the case of FLISR).

In the first case, Application Programming Interfaces (API) will be available for the user or for specific services to access the data when these are needed, or to write them in the database (these interfaces are in any case on the user or service side). For the part of real-time data storing, instead, a publish/subscribe mechanism is implemented. According to this logic, the database will be equipped with:

- **Database subscriber:** it is the software interface through which all the live data that have to be stored can be received via the message broker in the ViSA gateway. It is worth noting that, if different databases are implemented for storing different classes of real-time data, then each one will be equipped with a database subscriber that only subscribes to receive the live data of interest. In this way, it will be possible to distribute the storing data process among different entities fostering the scalability of the solution.

- **Database recorder:** it is the software component in charge of extracting the relevant information obtained through the Database subscriber and of writing it in the time-series database.

Figure 13 provides a view of the database persistence component and of the needed interfaces, according to the considerations reported above.

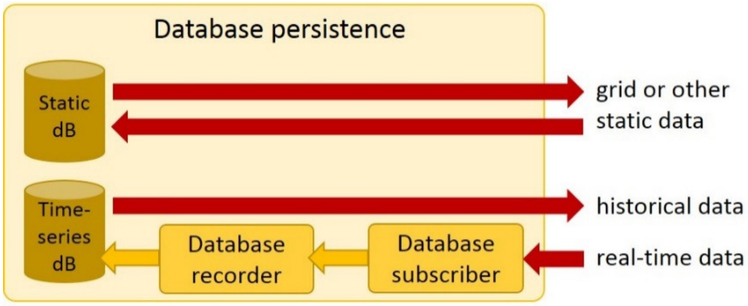

Figure 4: Schematic view of the software components in the ViSA database

3.4 Service component

The self-healing services need to receive data from the field components as well as the grid data for their operation (in case of FLISR). Once the service runs and produces results, those results need to be made available within the ViSA for triggering other possible services, for actuating some commands in the field, or simply for storing them in the database or visualizing them in the DSO user interface. As a result, specific interfaces are needed to enable the input/output communication of the service within the ViSA.

The FLISR and LP/GP services are conceptually very different: they require different types of data in input and they operate with different logics. As a result, they also require different interfaces. The description of these interfaces will be thus done separately in the following.

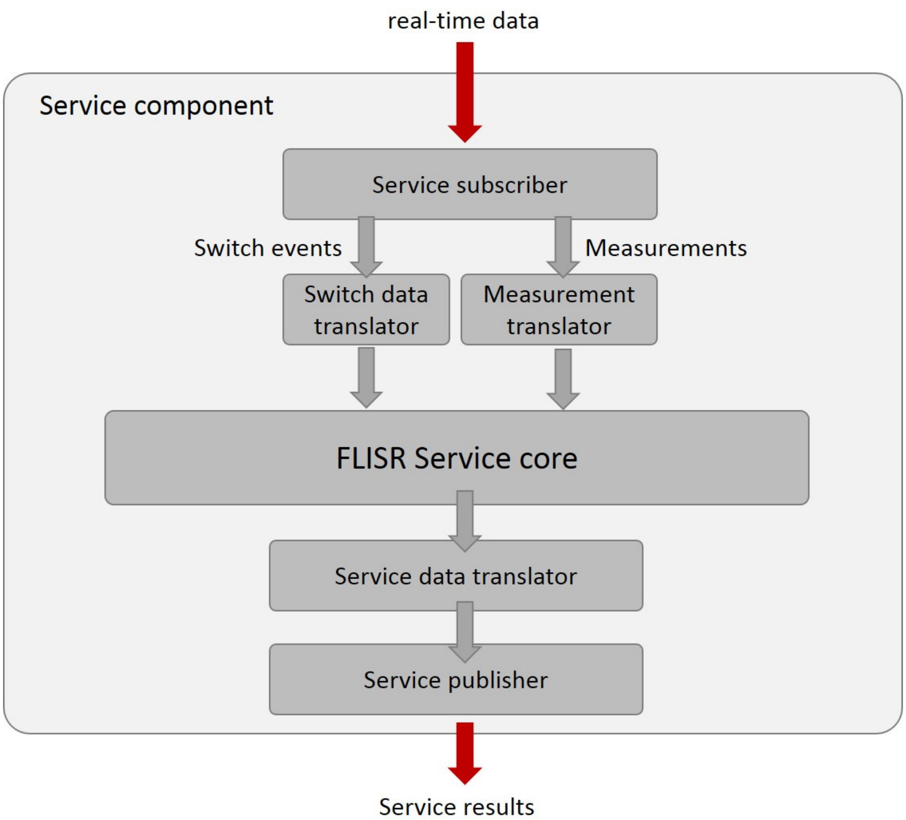

Figure 5: Schematic view of the interfaces for the FLISR service.

Concerning the FLISR service, Figure 5 shows a schematic view of the main software components needed as input and output interfaces during its real-time operation. It is important to highlight that, being based on the use of machine learning, this service has different requirements for the training phase and for its real-time operation. For example, for the training of the algorithm, detailed data about the grid are needed in order to run the power system simulations necessary to understand the behaviour of the electric system during fault conditions. However, once the training is completed and the algorithms are validated, no grid data are necessary anymore for the operation of the algorithm in real-time. As a consequence, since the training is usually performed off-line before the service deployment, no interfaces are needed in the ViSA deployment for the collection of grid data or for their processing. The only data needed during the live operation of the FLISR service are thus the real-time data that are received in case of fault occurrence in the grid. As indicated in the previous sections, real-time data are managed within the ViSA using a publish/subscribe mechanism. Consequently, the FLISR service requires a **service subscriber**, which is connected to the message broker in the ViSA gateway, for the collection of the real-time data of interest. In particular, two types of data are relevant for the live operation of the FLISR: the notification of switching events triggered by a fault, and the measurement data during the fault time period for the analysis of the fault. The first type of data (notification of switching events) is used by the FLISR service to understand if a permanent fault occurred in the grid. These notifications need therefore to be translated through a **switch data translator** from the original data format to the one required by the service for the internal processing. The second group of data are the measurements from the field: even in this case, a specific **measurement translator** interface is needed to convert the data format of the inputs from their original structure to the one used within the service.

In output, the FLISR produces different results: the first one is the location of the fault, which has to be sent to both the database and the visualization tool for guaranteeing the availability of this information for the grid operators; the second one is the set of opening/closing commands to be sent to the switches in the field for applying the fault isolation and the power supply restoration in the non-faulty areas. Both these outputs are produced and sent to the ViSA platform following the usual publish/subscribe logic, only applying different topics for differentiating them. From a logical perspective the series of steps (and interfaces) needed is therefore the same. First, a software interface (**service data translator**) will take care of the conversion of the service results into the data format used for the communication within the ViSA (for example relying on JSON data structure), and then the **service publisher** will accomplish the task of sending the result by assigning a specific topic to the data, wrapping them into the transport protocol used within the ViSA and finally establishing the communication and the sending to the message broker.

Regarding the LP/GP algorithms, these services only require historical information for their operation and there is no need for interaction with real-time flowing data. More in detail, the LP only requires historical data about the previous consumption of the considered customer; the GP requires the equivalent historical data of generation, together with the associated weather data. These data can be acquired by using a request/response communication with the database, which can be activated through specific APIs running as interfaces in the LP/GP service. The **LP/GP dB API** is therefore responsible for establishing the communication with the ViSA database and for retrieving the desired amount of historical data from the considered customer or photovoltaic plant. Once these data are acquired, an **historical data translator** is needed to convert the received data in the data format and structure desired internally to the service core. In parallel with this set of interfaces, the GP service also requires weather forecast information to produce the prediction of power generation. As a consequence, dedicated interfaces will be also needed to this purpose. Similarly to the previous case, since a request/response mechanism can be adopted to retrieve these data, a **LP/GP weather API** is needed for establishing the communication with the server having the information on the weather forecast and for pulling the required data. Then, an associated **weather data translator** will be again needed for the conversion of the collected data into the data format and structure used within the service core.

The output of the LP/GP service is the forecast (for example for the following day) of the consumption or generation for the considered node. This output is not needed to be visualized in real-time by the visualization tool, but it should be available for visualization in case the grid operator wants to control it. As a consequence, the output data need to be stored in the database for the possible use upon request. For writing the data in the database, the same dB interface used also for collecting the historical data can be used. The data in output thus has to go first through a **service data translator**, for its data format conversion, and then to the **LP/GP dB API**, which will take care of writing these results in the database.

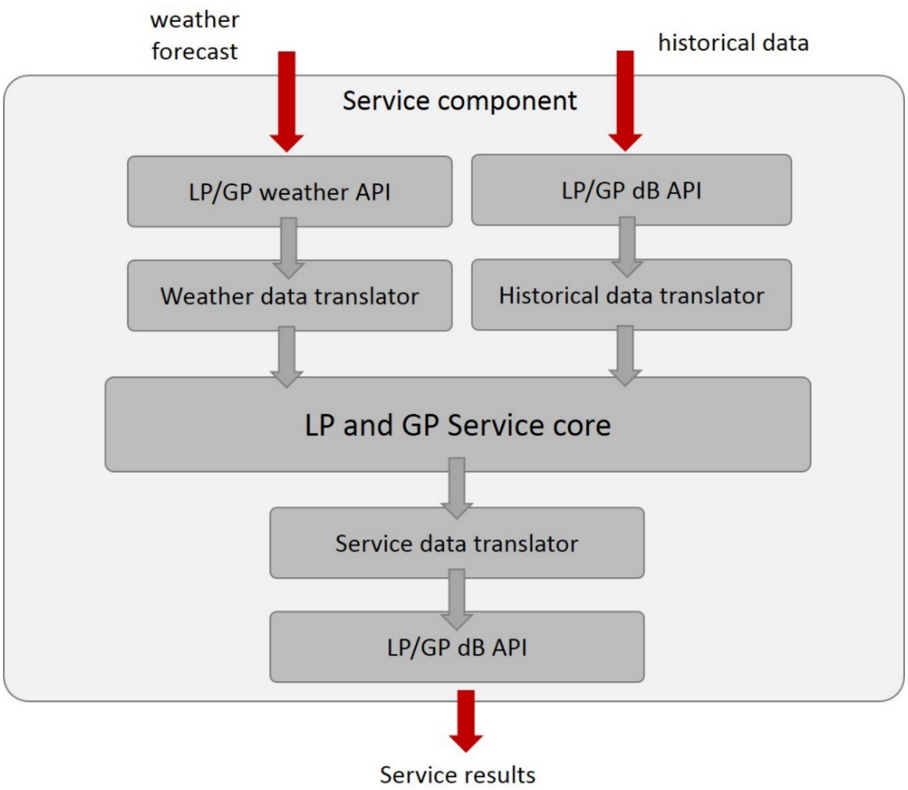

Figure 6: Schematic view of the interfaces for the LP and GP services.

3.5 Graphical user interface component

The Graphical User Interface (GUI) is an essential component of the SOGNO platform, since it is the place where all service results will be displayed to provide system awareness to the operators. Depending on the services, on the requirements of the DSOs, and on the functionalities provided by the ViSA platform (set of implemented services, additional data analytics tools available, etc.), the list of data to be processed and visualized in the user interface can largely change. In general, in the SOGNO solution, the results of the services running in real-time (like FLISR) will be forwarded to the GUI following the publish/subscribe mechanism, while other possible functionalities that need to access the data stored in the databases can be accessed via specifically developed APIs (like in the case of the load and generation predictions given by the LP/GP service). Following this philosophy, the interfaces needed by the GUI are:

- **GUI subscriber:** it is responsible for the subscription to the desired topics and it is the component where the results of the real-time services will be received via a publish/subscribe mechanism.
- **GUI data translator:** This interface is responsible for translating service results into the desired visualization objects and sending them to a client application where they can be displayed.
- **GUI API:** this indicates those software components responsible for accessing specific data sets from the ViSA database and for making them available to the GUI. The implementation and the specific functionalities can largely vary depending on the accessed data and on the information that has to be visualized in the GUI.

Figure 7 gives a schematic view of the interfaces needed for the visualization of the desired data into the GUI provided to the DSOs. Concerning the services described in this Deliverable, the output of the FLISR service (location of the fault) should be visualized in real-time in the GUI, while the power forecasts can be accessed via the GUI API upon request of the grid operator.

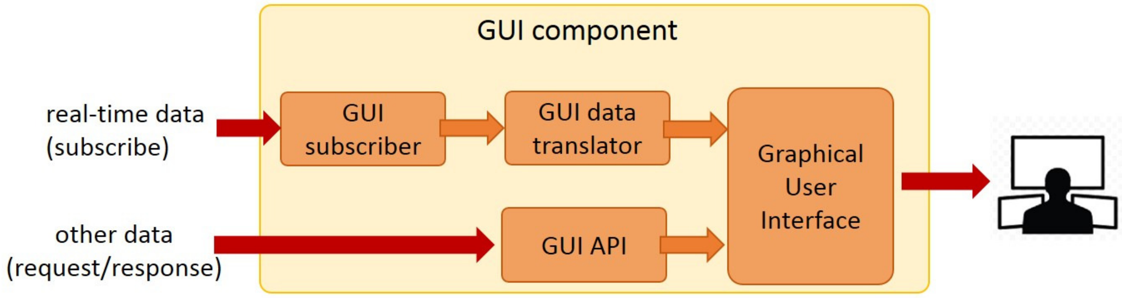

Figure 7: schematic view of the interfaces for the GUI component

3.6 ViSA services interaction architecture

Figure 8 shows the overall view of the ViSA services interaction from a logic perspective, highlighting the links among the different services. The different services receiving or sending data in real-time will use the publish/subscribe mechanism, while the services without real-time requirements will use the request/response paradigm. This combination of communication schemes allows the interaction of the services with the field, the actuation of bi-directional communication, and the possible coordination of different services. This is important not only for the possible coordination of different power system services, but also for integrating the power system services with data analytics tools that, using the results of the power system services, can provide further insight or details to the DSOs about events, behaviour and KPIs of their grid. This concept also allows highlighting one of the main benefits of the conceived architecture and of the ViSA platform, namely the possibility to flexibly interconnect different services in order to provide both automation functionalities and additional indexes or parameters to the DSOs.

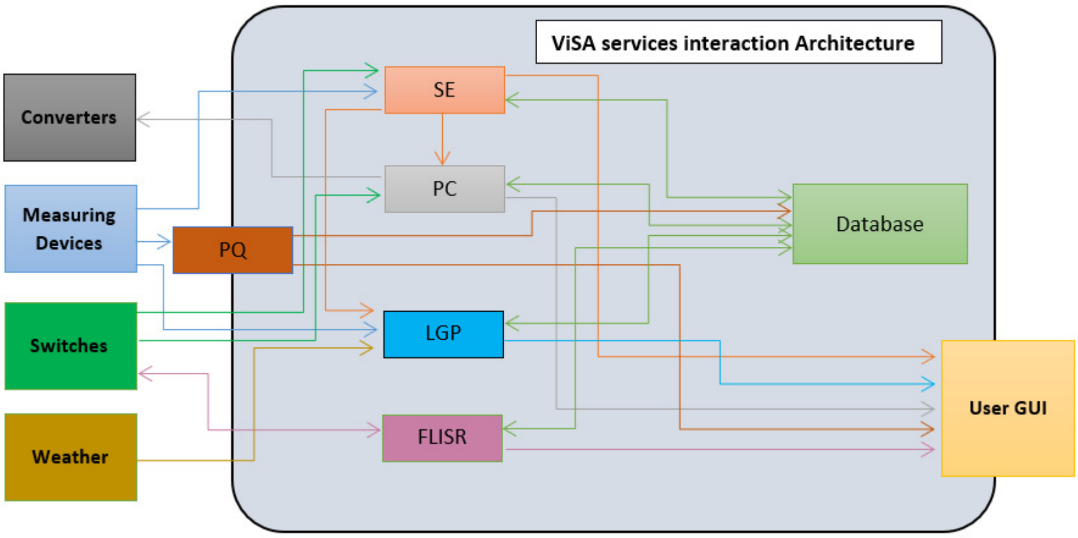

Figure 8: ViSA services interaction architecture

4. Conclusions

The presented ViSA platform allows the flexible integration of different components, power system services, data analytics tools, which are necessary or helpful for facilitating the work of DSOs and to give them all the tools necessary for the optimal management of their networks. The proposed ViSA solution can be flexibly integrated into existing DSO platforms or can be implemented by third-party companies for providing a turnkey solution to DSOs, according to the concept of “automation as a service” promoted by the SOGNO project.

The services described in this deliverable, LG/GP and FLISR, are the corner stones for operating the grid in a safe and reliable way. The prediction allows the early detection of upcoming problems and failures in the grid and gives the grids operators enough time for countermeasures. In the case of faults, FLISR will allow the quick and autonomous self-healing of the grid, cutting down the time of outage to a minimum.

For the project the development and description of these services allow the efficient implementation of the required service components and interfaces for all four platforms used in this project. The implementation finally enables the testing of these algorithms and services in the real grid to show the benefits in the day to day operation.

5. List of Tables

6. List of Figures

7. References

[1] M. M. Saha, R. Das, P. Verho and D. Novosel, "Review of fault location techniques for distribution systems," in *Power Systems and Communications Infrastructures for the future*, Bejing, China, 2002.

8. List of Abbreviations

ANN	Artificial Neural Networks
APMU	Advanced Power Measurement Unit
DSO	Distribution System Operator
FLISR	Fault Location Isolation and Service Restoration
LGP	Load/Generation Prediction
LPCT	Low Power Current Transformer
LPVT	Low Power Voltage Transformer
LV	Low Voltage
MQTT	Message Queuing Telemetry Transport
MV	Medium Voltage

ANNEX

A – FLISR inputs and outputs

A.1.1 FLISR static inputs

It is worth remarking that, in the FLISR service, grid data are required only during the training session of the algorithm but not during its real-time operation.

Table A-1: FLISR input requirements from grid data topology

	NODES	LINES	CABLE DATA
GRID DATA TOPOLOGY	Node ID	Line ID	Cable type ID
	Phases	Phases	Series resistance Ω/km
	Neutral grounding type	Neutral	Series reactance Ω/km
	Nominal Voltage [kV]	Start node ID	Shunt admittance μS/km
	Node type	End node ID	Shunt capacitance μF/km
	Node category	Phase cable type ID	Homopolar series resistance Ω/km
	Nominal Power [kVA]	Neutral cable type ID	Homopolar series reactance Ω/km
	Typical power factor	Length [km]	Homopolar shunt admittance μS/km
			Homopolar shunt capacitance μS/km

Table A-2: FLISR input requirements from grid data components

	SWITCHES	TRANSFORMER DATA	MEASUREMENT INFRASTRUCTURE
GRID DATA COMPONENTS	Switch ID	Trafo ID	Meter ID
	Switch type	Start Node ID	Location Line/Node ID
	Start Node ID	End Node ID	Monitored quantities
	End Node ID	Primary connection	Measurement accuracy
	Normal Status	Secondary connection	Reporting rate [meas/sec]
		Phase shift [degrees]	
		Primary voltage [kV]	

	Secondary voltage [kV]
	Nominal power [kVA]
	Short circuit voltage [%]
	Short circuit losses [kW]
	Open circuit current [%]
	Open circuit losses [kW]
	OLTC
	Tap range [%]
	Number tap steps
	OLTC regulation

A.1.2 FLISR real-time inputs

Table A-3: FLISR input requirements from switch and measurement devices

	NAME	MEASUREMENT UNITS	SWITCH
FOR EACH CONNECTED COMPONENT	Device ID	X	X
	Timestamp	X	X
	Opening action		X
	Closing action		X
	Measurements associated to fault	X	X

A.1.3 FLISR outputs

Table A-4: FLISR output results

	NAME
FLISR OUTPUT	Faulty branch or area
	Switch ID
	Actuation command

B – Load and Generation Prediction inputs

A.1.4 LP/GP Measurement inputs

Table A-5: LP/GP measurement inputs

	NAME	LOCOPMU	APMU
	Device ID	X	X
	Timestamp	X	X
FOR EACH CONNECTED PHASE	Voltage Magnitude	X	
	Voltage phase angle	X	
	Current magnitude	X	
	Current phase angle	X	
	Active power		X
	Reactive power		X

A.1.5 LP/GP Output

Table A-6: LP/GP output results

	NAME
FOR EACH CONNECTED PHASE	Active power consumed (generated) at future time slots
	Reactive power consumed (generated) at future time slots